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XI[th] SECTIONAL MEETING

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WORLD POWER CONFERENCE

YUGOSLAVIA BEOGRAD 1957 SWEDEN

THE SWEDISH SHALE AS RAW MATERIAL FOR PRODUCTION OF POWER, OIL AND GAS

by

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INTRODUCTION

The Swedish Shale Oil Company, with their plant located in Närkes Kvarntorp, Sweden, is the only company mining the Swedish oil shale for production of power, oil and gas.

The plant has been described in more detail in previous reports [1,2]. This paper is concerned more or less to give a comparison of the results attained with the different pyrolysis methods, in connection with a short presentation of the processes.

The company was founded during the second world war and production started in April 1942. When the project was planned, no one had any idea which pyrolysis method would be the most suitable for Swedish oil shale. Therefore, from the very start of plant design three different retort methods were included for pyrolysis of oil shale. Later on, a method was added for pyrolysis of the oil shale »in situ«. Since the start the plant has been continuously at work for more than 14 years. During this time better methods have been developed and practical experience acquired. A technical and economical comparison between the different methods, on the present engineering standpoint, may therefore be justified.

RAW MATERIAL

The richest Swedish oil shale is situated in the Province of Närke and originates from late-cambrian period. These deposits are divided into two areas and constitute a total quantity of 1,700 million metric tons. The

1957

rp plant is located at the shale deposit in the eastern part of the of Närke. Analysis of shale and ash, respectively, is shown in 1.

Table № 1.

Shale		Ash	
	18.0%	Si_2O	60.7%
	2.0%	Fe_2O_3	11.2%
	6.3%	Al_2O_3	22.5%
oisture	1.9%	K_2O	5.1%
h	71.8%	Na_2O	0.5%

e average calometric heating value varies between 2,000 and 2,200 r kg. (3,600—4,000 B.Th.U. per 1b.)

e yield of oil accordance to the »Fischer assay« amounts to an average ıd 5.7%. The raw gas, formed in addition to oil during the pyrolysis, eating value depending upon the method of pyrolysis, but of the same magnitude as the extracted oil. After the pyrolysis a coke remains ng around 50% of the heat content of the shale. The low fusing tem- of the ashes — around 950°C — makes combustion or gas generation esidual coke difficult.

HANDLING OF SHALE

is a pre-requisite for the industry, because the Swedish shale is a w material, that mining, crushing, screening and transport do not o large expenditures. The deposits in the eastern part of the province e are favourable. The shale seam is practically horizontal and has num thickness of 16 meters (50 ft.) It is 2 to 4 kilometers wide and ieters long in the east-west direction. In the deposit are layers of balls nious limestone to an amount of around 15%. The south portion of osit is covered by ordovicium limestone, which in similarity to the the northern part, is thinned down by erosion during a later epoch. one third of the deposit — the part that presently is mined — has no of limestone and instead has only an overburden of loose soil with age thickness of 7 m. (23 ft).

efly the handling of shale is as follows. The overburden is directly y a dragline, with a bucket of 8 m³ (11 cubic yards) and 60 m. (175 ft) radius, into previously mined areas. Blasting is done in 100 mm vertically drilled holes, so that the shale remains »in situ«. The shale d by powered shovels, capacity 4 m³ (5 cubic yard), and transported 20 ton trucks and then in similar size standard gauge railway cars. crushing is done by »Blakes« type jaw crushers and the intermediate by medium size »Simon« gyratory crushers and screening by conventional mechanically vibrated screens. After the coarse crushing the bitumious limestone is picked out by hand. Average efficiencies for the last few years computed on the basis of finished retort shale without bitumious limestone are shown in table № 2.

Table № 2

Required labour for shale handling	man hrs / 1000 ton	164
Specific maintenance expenditures	Swedish kronor / 1000 ton	1070
Consumption of explosives	kilograms / 1000 ton	112

The annual consuption of shale in the pyrolysis retort units the last years has been around 1,800,000 ton, which corresponds to 2,350,000 ton pure shale from the mine. Simultaneously »in situ« consumption has been around 900,000 ton of the deposit.

PYROLYSIS METHODS

1. **The I.M. or Tunnel Kiln Retort,** in which oil shale, screening size 30 to 80 mm, charged cars pass through a heating and pyrolysis zone in a tunnel. The gas enclosed in the tunnel circulates partly through the shale loaded cars and partly over pipe coils, in which as heating medium flue gas is circulating. This flue gas is generated in a separate gas — or oil fired furnace. The pyrolysis gas formed is drawn off, likewise the other methods, and oil vapour is condensed in a condensing unit adjacent to the kiln. Residual shale coke is discarged from the cars and burned in a separate unit. The IM-Kiln's part in the plant's total net production of crude oil, raw gas and steam, is around 11%.

Advantages:

a. The gas has a high heat value and a low percentage of oxygen. The design does not to any extent permit leakage of air or flue gas.

b. The kiln can be fired by either gas or oil in desired proportions. The plant's total gas production can thereby be utilized without burning excess gas in the boilers or in flares.

Disadvantages:

a. The kiln requires a large amount of fuel in proportion to its production. The kiln's own gas production, after hydrogen sulphide, light gasoline and liquefied petroleum gas (propane and butane) have been extracted, covers only about 30% of the required amount of heat.

. High maintenance and cleaning expenses. Construction difficulties due to temperature stress in the comparatively complicated tunnel . Further it is difficult to keep the cars running at high temperature. ng of heavy hydrocarbons in the circulating gas, cause deposits of coke ıting tubes and cars. This requires periodic shut-down for de-coking eaning.

The residual coke is of pyrofore nature and has to be burned and yed to avoid destruction of nearby vegetation. This requires a separate burning furnace[3], in which however superheated high pressure is generated.

HG-Retort is an improved Pumpherston furnace with 72 retorts modi- ır Swedish shale. Each retort is 9 m (30 ft) long and 600—700 millimeter : inches) in diameter. Shale, screening size 30 to 80 mm, is charged into hopper above the retort and the residual coke is continuously rged through the lower end of the retort. Flue gas, generated in te gas — or oil burners for each retort, is the heating medium, and .tes around the retort. The HG-Retort's part in the plant's total net :tion of crude oil, raw gas and steam, is around 10%.

dvantages:

. Yield of crude oil and raw gas is very high.

. The retort can be fired by either gas or oil in desired proportions. he plant's total gas production can thereby be utilized without burning gas in the boilers or flares.

isadvantages:

A certain inescapable dilution of pyrolysis gas with flue gas can not ıided, due to flue gas leakage through the retorts.

In proportion to the retorts'own production the retorts require a large amount of fuel. Each retort's gas production, after hydrogen le, light gasoline and liquefied petroleum gas (propane and butane) een extracted, covers only around 75% of the required amount of heat.

The residual coke is of pyrofore nature and has to be burned and ·ed to avoid destruction of nearby vegetation. This requires a separate burning furnace[3], in which however high pressure superheated is generated.

The Kvarntorp-Retort is a modification of the Bergh Retort, fig 1, signed especially for the Swedish oil shale. The shale, screened size ; mm, is charged into an open hopper, from which the shale passes ı a large number of small retorts, 2.2 m (7 ft 3 inches) long and 200— limeter (8—9 inches) in diameter. The shale is discharged into combus- ambers from the lower end of the retorts. The combustion gases ɜ the necessary amount of heat for the pyrolysis, and therefore no source of fuel is required. On account of the low fusing temperature spent shale, separate La Mont heat absorption coils[3] are installed in the combustion chambers, and in these coils high pressure steam is generate or superheated. The Kvarntorp retort's part in the plant's total net produ tion of crude oil, raw gas and steam, is around 60%.

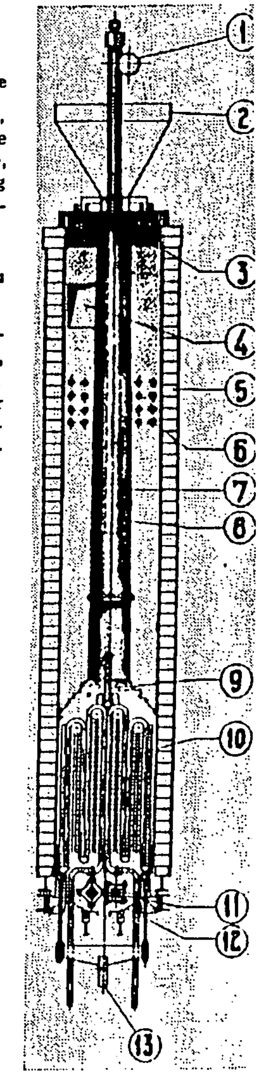


Fig. 1 — Section through shaft in the Kvarntorp furnace

1 — Gas header, 2 — Charging hopper, 3 — Insulation, 4 — Flue gas outlet, 5 — Brick walls, 6 — High-pressure steam generating coils, 7 — Retort, 8 — Gas suction tube, 9 — Low-pressure steam distributor, 10 — Heat-absorbing surfaces in fuel bed, 11 — Discharging rollers, 12 — Discharging guide plates, 13 — Vibrator

Fig. 1 — Section de la couche de combustible d'un fourneau Kvarntorp

1 — Collecteur de gaz, 2 — Trémie de chargement, 3 — Isolant thermique, 4 — Sortie des fumées, 5 — Murs de briques, 6 — Serpentins générateurs de vapeur à haute pression, 7 — Cornue, 8 — Tube d'aspiration du gaz, 9 — Distributeur de vapeur basse pression, 10 — Surfaces absorbantes de chaleur dans la couche de combustible, 11 — Rouleaux de déchargement, 12 — Plaques de guidage du déchargement, 13 — Vibrateur

Fig. 1 — Querschnitt durch einen Schacht des Kvarntorpsofens

1 — Gassammelsrohr, 2 — Schiefertrichter, 3 — Isolterung, 4 — Rauchgaskanal, 5 — Schachtwände aus Ziegel, 6 — La Mont Kühlrohre, 7 — Retorte, 8 — Gasaussaugungsrohr, 9 — Niederdruckdampfverteiler, 10 — La Mont Kühlrohre im Koksverbrennungsschacht, 11 — Walze für Entfernung von Schieferasche, 12 — Bleche für Regelung der Entfernung der Schieferasche, 13 — Vibrator

Фиг. 1 — Разрез шахты печи „Кварнторп"

1 — Труба для отвода газа, 2 — Резервуар для добавки сланца, 3 — Изоляция, 4 — Выход дымового газа, 5 — Кирпичные стены шахты, 6 — Охлаждающие трубы „Ла Монт", 7 — Реторта, 8 — Выход для газа, 9 — Распределитель пара низкого давления, 10 — Охлаждающие трубы „Ла Монт" в шахте для изжигания кокса, 11 — Цилиндры для вычерпания печи, 12 — Листы для вычерпания печи, 13 — Вибратор.

Advantages:

a. The furnace is producing adequate amount of heat for the pyrolysis.

b. High pressure superheated steam is generated without intermediate steps.

c. The yield of crude oil and raw gas is the highest in this type of retort, provided that the production from the other furnaces is corrected for the fuel concerned.

The retort is better suited for finer crushed shale than IM- and orts.

The furnace has proved to have extensive development possibilities. iginal Bergh-retort has been altered to such extent that production :reased 150% in the same unit[3]. Available experimental test data additional production increase of 50%. In consequence of this data orts are presently altered in accordance therewith, and no operating :an therefore be rendered in this paper.

isadvantages:

The raw gas has a low heating value. The reason is a large leakage and flue gas into the open ends of the retorts.

The furnaces are composed of many small parallel connected retorts, 1 3920, making it difficult to control the furnaces. In spite of this, the ours in *proportion* to production is the lowest in this type of the three in use.

Exceptional wear of heating coils.

The Ljungström method[4] involves electrothermal heating for pyro- in situ«. Through hexagonally spaced electric underground heaters the is heated *to pyrolysis temperature*, and the gas is collected through lly spaced underground pipes. This method's part in the plant's total oduction of crude oil, raw gas and steam, is around 19%. Therewith ion has not been done for used electric energy.

dvantages:

Obviously shale mining, crushing and any other handling of shale ihes is not required.

Investment in plant is small.

Products are lighter than by the use of the retort methods giving paratively larger yield of gasoline and liquefied petroleum gas (propane itane).

isadvantages:

Heating is done by electricity, with a large consumption of rather ive energy. The economy of the method is largely dependent on a supply of electric power, for which reason hydroelectric power is a *te for this method.*

The process is sluggish. It takes around half a year from the beginning ling period to full exploitation of the field.

The method has a definite premise as to form and position of the oed. A horizontal not too deep lying shale bed under a cover of non-s rock is necessary.

detailed production and technical comparison on the basis of equi- yield — and consumption figures are illustrated by the diagram fig. , — 4 and 5.

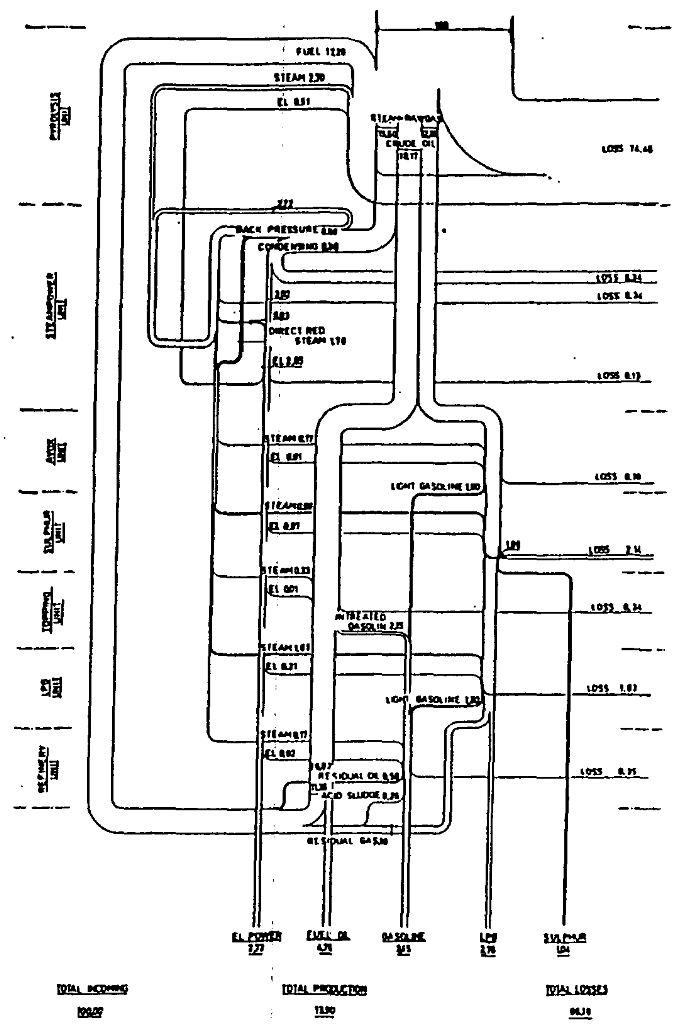


Fig. 2 — Sankey-diagram for oil-shale pyrolysis according to the IM Method and for the refining of crude products therefrom

Fig. 2 — Diagramme Sankey relatif à la pyrolyse du schiste par la méthode IM et au traitement consécutif des demiproduits qu'elle donne

Fig. 2 — Sankey-Diagramm für Schiefer-pyrolyse mit IM-Metode und für Weiterverarbeitung der dabei erzeugten Halbfabrikate

Фиг. 2 — Диаграмма „Санки" (Sankey) для пиролиза сланца по методу в туннельных печах и для дальней обработки при том полученных полу-фабрикатов

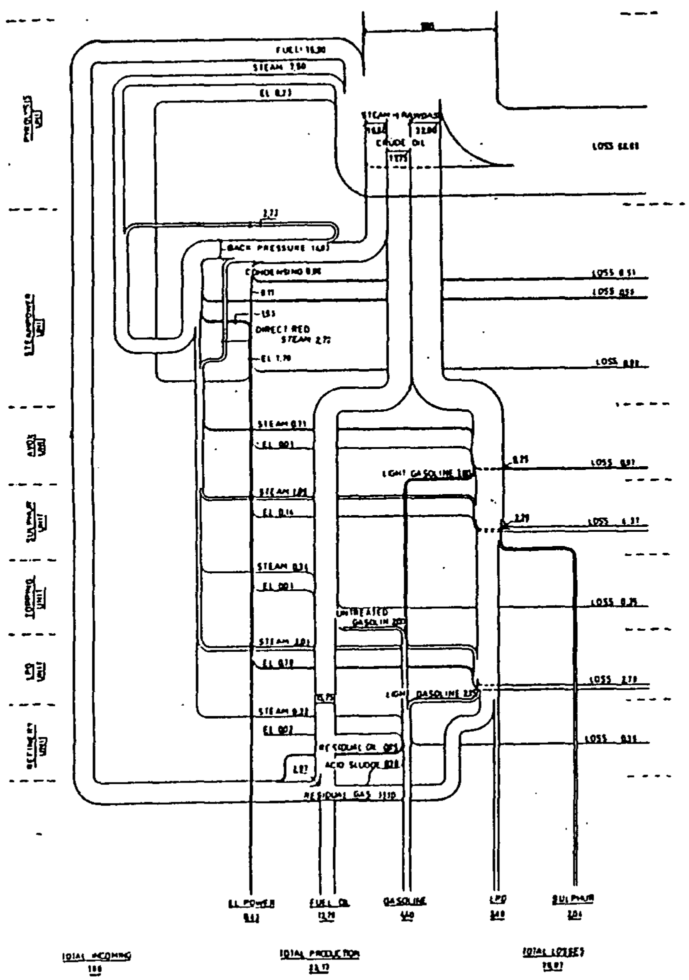


Fig. 3 — Sankey-diagram for oil-shale pyrolysis according to the HG Method and for the refining of crude products therefrom

Fig. 3 — *Diagramme Sankey relatif* à la pyrolyse du schiste par la méthode HG et au traitement consécutif des demiproduits qu'elle donne

Fig. 3 — Sankey-Diagramm für Schiefer-pyrolyse mit HG-Metode und für Weiterverarbeitung der debei erzeugten Halbfabrikate

Фиг. 3 — Диаграмма „Санки" (Sankey) для пиролиза сланца по методу „ХГ" (HG) и для . . . (см. предидущее)

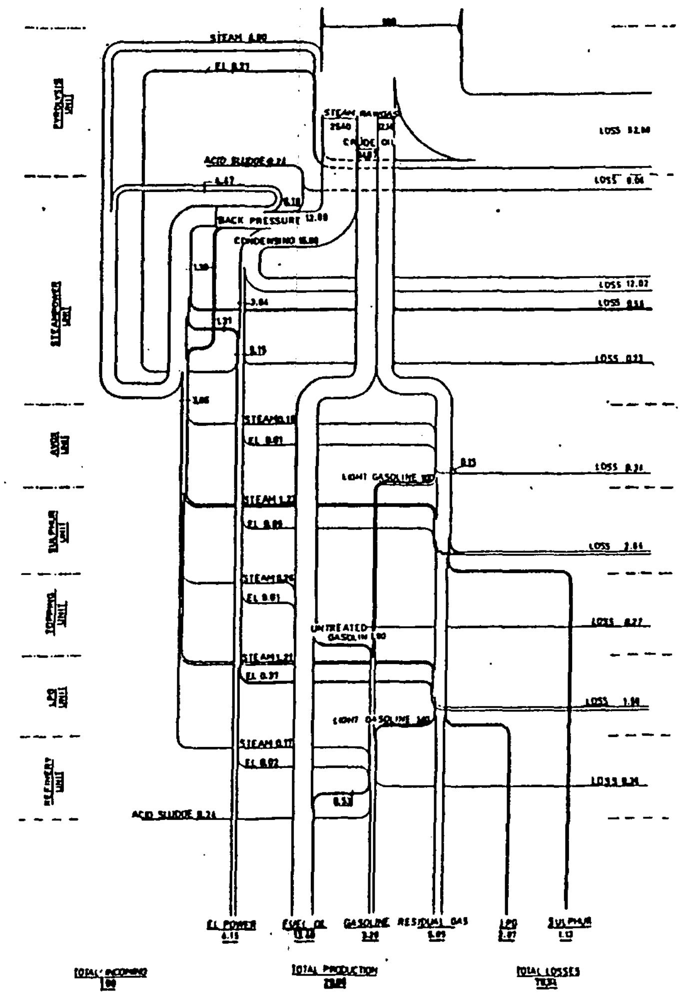
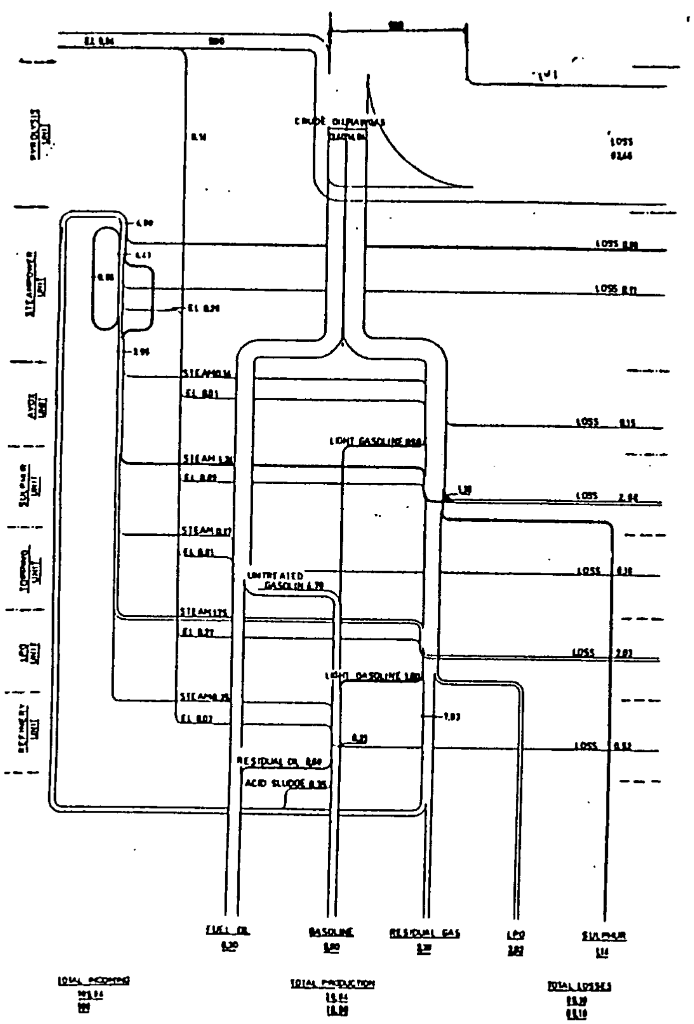


Fig. 4 — *Sankey-diagram for oil-shale* pyrolysis according to the Kvarntorp Method and for the rifining of crude products therefrom

Fig. 4 — Diagramme Sankey relatif à la pyrolyse du schiste par la méthode *Kvarntorp et au traitement* consécutif des demi-produits qu'elle donne

Fig. 4 — Sankey-Diagramm für Schiefer-pyrolyse mit Kvarntorp-Metode und für Weiterverarbeitung der dabei erzeugten Halbfabrikate

Фиг. 4 — Диаграмма . . . (см. предидущее) . . . *методу „Кварнторп"* и для . . . (см. предидущее)



. 5 — Sankey-diagram for oil-shale pyrolysis according to the Ljungström Method and for the refining of crude products therefrom

. 5 — Diagramme Sankey relatif à la pyrolyse du schiste par la méthode Ljungström et au traitement consécutif des demi-produits qu'elle donne

. 5 — Sankey-Diagramm für Schiefer-pyrolyse mit Ljungström-Metode und für Weiterverarbeitung der dabei erzeugten Halbfabrikate

. 5 — Диаграмма .. (р.) .. методу „Юнгстрём" и для .. (см. пр.)

By a comparison between the different pyrolysis methods certain specific values can be to a good guidance. Such comparative values for the last three years are shown in table № 3. As basic number for the various figures has been used produced million Mcal in form of crude oil, raw gas and steam. Regarding production of steam from residual shale coke, this is accomplished either direct or in a separate coke burning furnace[3]. In the latter case the required labour and maintenance costs are divided on the IM- and HG-Retorts, in proportion to delivered quantity of coke.

Table № 3

		Pyrolysis methods			
		IM	HG	Kvarntorp	Ljungström
Required labour	Man hrs / million Mcal	780	630	220	290*)
Maintenance	Sw. Kronor / million Mcal	4300	2900	1200	960*)
Availability	%	80	93	94	94

*) In these cases consideration has not been taken to the consumption of electric energy, wherefore the produced Mcal is not net yield.

FINISHED PRODUCTS UNITS

In the Kvarntorp plant refining of the crude products from the pyrolysis units is done in more or less conventional units. Only a brief description of the different units seems justified in connection with this paper.

1.**The steam Power Unit** is basing its activity upon the generated high pressure superheated steam (25 atm. pressure and 350°C) from the La Mont system inserted in the Kvarntorp retort furnace and the separate shale coke burning furnace. The generated steam goes through an 8 MW back pressure turbine. Normally 70 t/h, 25 atm. steam is going through this turbine producing around 6 MW and 5 t/h 11 atm., and 65 t/h, 3.5 atm. is delivered as process and utility steam for the plant. The surplus steam goes to condensing turbines of 8 respectively 12 MW. Around 150 million kWh has been generated yearly the last few years.

2. **The Avox Unit**[5] is based on a process of selective catalytic combustion of hydrogen with oxygen in the raw gas — normally 1.0 to 1.5% O_2. The unit was fully processed, developed and designed by Kvarntorp employees. The oxygen is removed because it has a detrimental chemical effect and causes severe corrosion in subsequent units. Part of th 'ight gasoline

ırbed before the raw gas enters this unit to avoid condensation in ng processes.

The Sulphur Recovery Unit is a conventional alcazide process for ion of H_2S from raw gas. The H_2S is converted into elementary r by the well known »Claus« process. The annual production in the w years has been around 30,000 ton.

The Liquefied Petroleum Gas (LPG) Unit is a conventional absorption , in which light gasoline, propane and butane are absorbed under . pressure. Before this absorption process organic sulphur compounds ıverted to H_2S by a catalytic process, after which the H_2S is absorbed ɔnventional etanolamine scrubber. The annual production the last few ıas been around 11,000 ton. LPG.

The Topping Unit is a common atmospheric distillation. The annual tion the last few years has been around 72,000 m³ (450,000 bbl) fuel oil.

The Refinery Unit is an ordinary sulphuric acid process, modified to ıe special character of the shale gasoline. The annual production the w years has been around 28,000 m³ (175,000 bbl petrol)

SANKEY DIAGRAM FOR THE KVARNTORP PLANT

o bring about a comparison between the efficiency of the different ds in Kvarntorp, complete Sankey diagrams, fig. no. 2, 3, 4, and 5, have leveloped for the whole plant based on previous production results. In ıse each product, regarding raw material, production, consumption as s losses, has been expressed in heat equivalents. Presuming that the e heat content of the shale is 2,000 kcal/kg, this corresponds to 100 lents in the diagrams. The Sankey diagrams, one for each method, is a of the production balance for a shale oil plant, based on each of the yrolysis methods.

ecause the finished products have different values in each country, ı this connection no prolonged discussion take place regarding this rison. It should nevertheless be mentioned that the Kvarntorp retort , which has been the most developed, is superior to the other methods. ıperiority of this system will probably be still more eminent in counvhere the electric energy is relatively expensive and mainly depending rmoelectrical energy sources.

THE SHALE OIL

s previously said, the oil products in Kvarntorp are fuel oil and gaso-ıaracteristics of the oils are shown in table № 4.

Table № 4

Standard-analysis of topped oil				
			Ljungström oil	Retort oil
Spec. gravity	d_y^{20}		0.934	0.997
ASTM-dist				
	Fd	°C	187	185
	5		203	219
	10		211	234
	20		224	259
	30		298	281
	40		255	308
	50		265	331
	60		280	351
	70		291	373
	80		315	378
	90		341	
	95		364	
	End point		383	
	Overdist.	%	98	
	Rest	%	1	
Viscosity est				
		100°F	3.65	25.0
		210°F	1.34	3.33
Pour point		°C	< —60	—39
Ash		%	< 0.01	< 0.01
Carbon residue (Conradson)		%	0.35	4.6
Asphalt		%	0.03	0.79
S		%	1.19	2.05

What one especially notices regarding the oil from the Ljungström method is that the oil is essentially lighter than oil from the other methods.

The shale oil has, independently of the pyrolysis methods, a high proportion of aromatics, as shown in table № 5.

Table № 5

Type analysis of the dieseloil fraction from retort oil	Rel. number C-atoms %
Aromates	35
Naphtenes	45
Paraffines	20
	100

'he heavy oil from the retort method with a boiling point above 350°C ıngly aromatic and has a hydrogen content of only 8.4%. In this regard l is not suitable either for diesel oil or raw material for cracking or ating oil. Thus no fractionation is done, and the topped oil is presently :s fuel oil. For further refining of the heavy oil is now proposed a coking ınd research work in this connection is now under way.

ŀegarding the gasoline can be mentioned that with conventinal additives ıalities are delivered: Research Octane № 88 and research Octane № 93.

SHALE GAS

'he raw gas, formed in the pyrolysis, has, depending on the pyrolysis d, rather various characteristics and composition as shown in tables nd 7.

Table № 6

over particular data showing the varities in the production chain of generated gas by each method

	After pyrolysis	After Avox	After Sulphur unit	After LPG unit
quantity in cubic · per ton shale				
ırp-retort	45.0	42.3	32.6	30.4
ırt	98.0	95.0	75.6	72.6
:t	30.0	29.4	21.0	18.0
öm method	35.0		26.3	23.2
ıeating value in :ubic meter				
rp-retort	5,400	5,180	5,230	3,290
rt	4,670	4,440	4,420	3,060
·t	8,200	7,700	8,750	5,680
5m method	8,550		9,100	6,850

Table № 7 — Table of analyses showing the varieties in the production chain for generated gas by each method

	Kvarntorp retort				HG-retort				IM-retort				Ljungström method			
	After pyrolysis	After Avox	After Sulphur unit	After LPG unit	After pyrolysis	After Avox	After Sulphur unit	After LPG unit	After pyrolysis	After Avox	After Sulphur unit	After LPG unit	After pyrolysis	After Avox	After Sulphur unit	After LPG unit
N_2 vol %	33.2	35.3	45.8	49.2	26.7	27.5	34.3	36.0	11.3	11.5	16.1	18.8	4.0		5.3	6.0
O_2	1.8	—	—	—	0.9	—	—	—	0.3	—	—	—	—		—	—
CO_2	5.7	6.1	5.1	5.5	10.6	10.9	8.9	9.3	6.8	6.9	6.3	7.3	2.8		2.6	3.0
CO	0.8	0.9	1.1	1.2	1.2	1.2	1.5	1.6	0.8	0.8	1.1	1.4	1.1		1.5	1.7
H_2	14.9	12.0	15.6	16.8	24.6	23.6	29.3	30.8	17.1	16.8	23.5	27.4	20.0		26.6	30.1
H_2S	19.6	20.8	—	—	15.5	16.0	—	—	25.6	26.1	—	—	24.0		—	—
CH_4	13.4	14.2	18.5	19.9	12.6	13.0	16.2	17.0	17.7	18.1	25.3	29.5	29.9		39.8	45.0
C_2—	5.0	5.3	6.9	7.4	3.9	4.0	5.0	5.3	9.4	9.6	13.4	15.6	9.4		12.5	14.2
C_3—	2.7	2.9	3.8	—	2.0	2.1	2.6	—	5.5	5.6	7.9	—	4.6		6.1	—
C_4—	1.5	1.6	2.1	—	1.0	1.0	1.3	—	3.1	3.2	4.4	—	2.4		3.2	—
C_5 — C_6—	1.4	0.9	1.1	—	1.0	0.7	0.9	—	2.4	1.4	2.0	—	1.8		2.4	—

values for raw gas given in the tables for each one of the pyrolysis have been computed under the theoretical assumption that each andled separately in the products units, although this of course is : practically. Of particularly great interest is the gas after the LPG the Kvarntorp plant it has been shown advantageous to add a unit roduction chain for ammonia, and this unit went on stream in No- :956. Necessary operating data to be presented in this paper are not at the present time. It can however be of interest to review the : for production of ammonia on the basis of shale gas a little more On account of leakage of air and flue gas, especially with the Kvarn- ›rt method the raw gas is diluted with nitrogen. It is evident that ortion N_2 to H_2 if the hydrocarbon formed is steam cracked and the ıonoxide is converted to carbon dioxide and hydrogen, will be about :he resulting mixed gas after the LPG unit, and is suitable for pro- of ammonia. For any other synthesis the nitrogen would be only . The nitrogen content is a little too low, but this can easily be cor- , addition of some air in the hottest zone of the cracking unit. The content is always too low in the raw gas from IM-, HG- and the ›m methods, but in the raw gas from the Kvarntorp method the ni- ›ntent is a little too high. Previously in this paper has been talked reconstruction of the Kvarntorp furnace unit, and in this reconstruc- ns will be taken to lessen the leakage of air, so that even this gas, mixing, will be suitable for production of ammonia.

other circumstance which is speaking for production of ammonia step in the production chain, is that thanks to the Kvarntorp method, a surplus of steam, and in conjunction therewith, likewise power. ,ever, under the presumption that the electric energy supply to the ›m unit is arranged in some other way,for instance through buying electric power.

STEAM AND POWER PRODUCTION

account of the shales low hydrogen content, remains half of the e in the form of coke after the pyrolysis. With the retort methods the ›n of coke is accomplished, but in the case of the Ljungström t is not utilized.

ashes, around 87% of the coke, has a fusion temperature of 950°C ›fore an abnormal rise in temperature should be checked. This is equally distributed cooling coils in the combustion chambers. The is low, and around 6% of the coarse coke from the IM- and HG- and around 4% of the finer coke from the Kvarntorp retort units, rned. An other difficulty with the combustion of the shale coke is sulphur content. The ratio S:C $\cong$ 4:11 is very high compared with nal fuel. In consequence of this, the SO_3 dewpoint is high, around °C. The combustion gases can therefore not be cooled lower than to e cooling coils are exposed to corrosion and abnormal wear, because the design pressure does not correspond to a higher temperature than the dewpoint.

In an industry, where the chemical products is the essential thing, the steam pressure is selected more in consideration of operating safety than to power production. Unfortunately, when the Kvarntorp project was planned, nobody did anticipate any trouble or had any practical experience regarding this dewpoint, and therefore the plant has a very low power production in comparison to available fuel.

CONCLUSION

This paper is based on practical experiences and actual operating results have been presented. It has been shown that the Kvarntorp retort method, with no exception, is superior to any known method for pyrolysis of the Swedish oil shale. The Kvarntorp plant has at present passed the remunerative line, considering that production to certain extent is not done in rational units. In a recently published report[6], by a Swedish government committee, regarding future development of fuel and energy sources, attention is paid to the shale oil industry by a recommendation of extensive increase in plant facilities and production. This signifies, among other things, that successively operation will be converted only to the Kvarntorp retort method and complemented with eventual new methods primarily for pyrolysis of shale breeze, screened under 5 millimeter. The production program will be developed toward a higher refining:

1. The oil will be converted into motor fuel and coke.

2. The gas will be treated in accordance with previously stated methods but will also be used for hydrogenation of oils.

3. Power production will be increased by increasing the steam pressure to 79 atm. and the temperature to 450°C, in the operating units. By closing down the Ljungström unit and replacing it by additional Kvarntorp retort furnaces, the present annual power demand of 160 million kWh purchased from outside source, would be replaced by a net production of 200 million kWh.

This program signifies that Swedish oil shale will become a technically and economically competable raw material.

SUMMARY

The Swedish shale has a heat value of 2000 kcal/kg (3600 B.Th. U/1b), and an oil content of around 5.7% and produces by pyrolysis, besides the oil, also a gas with about the same heat content as the oil. The solid residue after the pyrolysis, the coke, has a heating value of 1000 to 1100 kcal/kg (1800 to 1980 B.Th. U./1b). The shale oil plant was constructed in the years 1941 and 1942 and was equipped with four different methods for pyrolysis, which have been improved during the years. Subsequently several unit for refining of

termediate products have been erected and so Kvarntorp has developed and more to a chemical industry on shale basis.

esults and experiences are given from the production and particular it is devoted to a comparison between the various methods for pyrolysis. ic data are given and in addition a complete energy balance is shown e whole production chain in the form of Sankey diagrams, one for ne of the pyrolysis methods. The data demostrate that the improved method developed in Kvarntorp, the Kvarntorp furnace, gives the esults.

he main products in Kvarntorp are oil, gas and steam. The oil is highly tic and at present is delivered as fuel oil and gasoline. The gas is used oduction of sulphur, propane, butane and ammonia. The steam from varntorp furnaces covers the demand of process steam within the plant ie excess is used for power generation.

RÉSUMÉ

e schiste suédois a une valeur calorifique de 2000 kcal/kg, une teneur en combustible d'environ 5,7% et donne, à la pyrolyse, en plus de l'huile, : du même équivalent calorifique que l'huile environ. Le résidu solide pyrolyse — le coke — a une valeur calorifique de 1000 à 1100 kcal/kg. d'huile schisteuse à Kvarntorp a été construite en 1941—1942 et a été le de 4 méthodes de pyrolyse différentes, qui se sont développées au des années. En outre, on a établi plusieurs sections pour le perfection- t des produits demi-fabriqués, de sorte que, de plus en plus, Kvarn- st devenu une entreprise industrielle chimique basée sur l'exploitation iste.

n dispose maintenant du résultat et des expériences acquis au cours production, et on s'est surtout intéressé à comparer les différentes mé- de pyrolyse. D'une part on présente des renseignements de détail d'autre part une balance complète d'énergie pour toute la chaine de tion sous forme de diagrammes Sankey, un pour chacune des métho- pyrolyse. De toute évidence, la méthode Bergh — le fourneau »Kvarn- — qu'on a continué à développer à Kvarntorp, donne le meilleur t.

s produits principaux de Kvarntorp sont: huile combustible, gaz et L'huile est très aromatique et, jusqu'à nouvel ordre, elle est délivrée huile combustible et essence. On raffine le gaz en soufre, gaséol et laque. La vapeur des fourneaux Kvarntorp pourvoit aux besoins de qu'exigent les procédés de fabrication, et de l'excédent on tire de e.

ZUSAMMENFASSUNG

r schwedische Schiefer hat einen Wärmewert von 2.000 kcal/kg, einen t von ca. 5,7% und ergibt ausser dem Öl ein Gas mit ungef. dem Wärmeinhalt wie dem des Öles. Der feste Pyrolyserückstand — Koks — hat einen Wärmewert von 1.000 bis 1.100 kcal/kg. Das ölwerk Kvarntorp wurde in der Zeit von 1941—1942 gebaut und mit rschiedenen Pyrolysemethoden ausgerüstet, welche im Laufe der vieterentwickelt wurden. Ferner sind viele Abteilungen zur Verede- r Halbfabrikate hinzugekommen, so dass Kvarntorp immer mehr eine he Industrieanlage auf Schieferbasis geworden ist. Ueber die Resul- d Erfahrungen aus der Produktion wird in diesem Bericht Rechen- bgelegt, wobei besonders dem Vergleiche der verschiedenen Pyrolyse- n Aufmerksamkeit gewidmet wird. Teils werden spezifische Daten teils wird eine kompl. Energiebalance für die gesamte Produktionskette in Form der Sankey-Diagramme gezeigt und zwar für jede Pyrolysemethode getrennt. Es hat sich herausgestellt, dass der »Kvarntorp«-Ofen, hervorgegangen aus dem »Bergh«-Ofen das beste Resultat gibt.

Die Hauptprodukte in Kvarntorp sind Öl, Gas und Dampf. Das Öl ist stark aromatisch und wird weitergeliefert als Verbrennungsöl und Benzin. Das Gas wird zu Schwefel, Gasol und Ammoniak weiterverarbeitet. Der Dampf aus den »Kvarntorp«-Öfen deckt den Bedarf an Prozessdampf und aus dem Ueberschuss wird Energie erzeugt.

РЕЗЮМЕ

Шведский сланец содержит — тепла 2.000 килокал./кг., масла 5,7% и дает при пиролизе кроме масла так-же газ, примерно того-же содержания тепла как масло. Твердый остаток после пиролиза — кокс — содержит от 1.000 до 1.100 килокал./кг. тепла. Предприятие обработки сланцев в Кварнторпе построенно в 1941-42 г-ах и имеет четыре различные способа пиролиза, которые далее развиты в течении годов. Дальше пристроенно много цехов для обработки полу-фабрикатов, так что Кварнторп все больше превращается в химическую промышленность на основе сланца.

Результаты и опыты настоящим опубликуются, причем особый интерес уделяется различным методам пиролиза. Выдаются специфические данные а так-же показывается полный баланс энергии целой цепи производства в форме диаграммы „Санки" (Sankey), одной диаграммы для каждого способа пиролиза. Оказывается, что далее обработанный метод Берга — т. н. „печ Кварнторп" — дает лучшие результаты.

Основные продукты в Кварнторпе — масло, газ и пар. Масло сильно ароматичное и вырабатывается в форме горючего масла и бензина. Газ обрабатывается в серу, т. н. „газол" и аммиак. Пар из печей Кварнторпа обеспечивает потребность пара для производства, а излишек превращается в энергию.

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